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SPIN CORRELATION IN PP SCATTERING AT 200 MeV

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The purpose of the project (CE35) was to test the feasibility of precision experiments with an internal polarized H gas target in the Cooler synchrotron, and to measure pp spin-correlation parameters at a bombarding energy near 200 MeV. Data acquisition has been completed, thanks to a very successful run in October 1994 which took advantage of improved machine operation and a number of other advances in experimental technique. The results described below are based largely on this one-week run.

The experimental arrangement consists of an atomic beam source that injects 3.1×10^{16} polarized H atoms/s into a target cell with thin Teflon walls. The target cell has cross sectional area 8 mm $\times$ 8 mm and a length of 254 mm. The wall is thin enough (450 μg/cm^2) for low energy recoil protons to be detected by silicon strip detectors which surround the target cell. The detectors are positioned at azimuthal angles of $\phi = \pm 45°$ and $\pm 135°$. Two detectors are placed at each azimuthal position. Each silicon strip detector is 4 cm wide by 6 cm long and is divided into 28 strips along the beam direction to provide information about the z-coordinate of the interaction.

Protons scattered in the angular range 3° to 18° are detected by a stack of forward detectors consisting of two planes of wire chambers and a scintillator. The trigger requires a coincidence between the forward stack and at least one of the recoil detectors. The four coordinates in the wire chambers plus the position signal from the silicon detector permits a determination of the scattering angle θ, the azimuthal angle ϕ, as well as the z-position of the vertex by a least-square fit.

An absolute energy calibration of each silicon strip detector is provided by ^{241}Am α-sources that are installed permanently near each detector. Since these are non-coincident events, this requires observation of singles in the silicon strip detectors. It is interesting to note that the singles rate is low even in the presence of the beam through the target. The 10 Hz α-sources produce a peak that is a factor 10 above pulses from pp events and background. Thus the fear that the intense circulating beam only 5 cm away from the silicon detectors would produce a large background turned out to be unfounded.

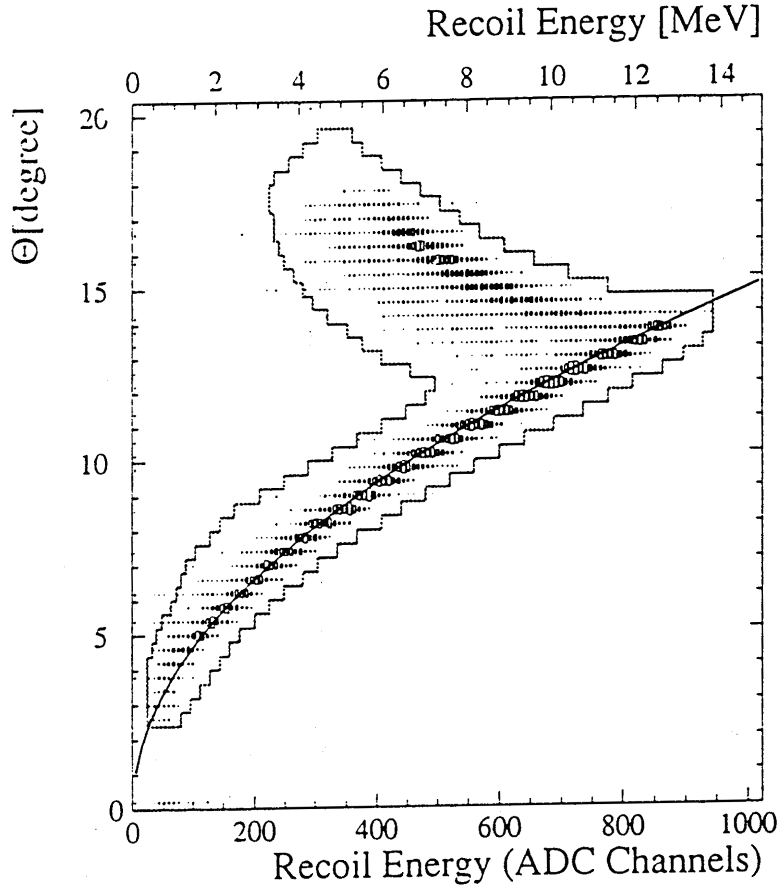

Figure 1. Pulse height in one of the Si strip detectors vs. forward scattering angle θ. The dashed line is based on an absolute energy calibration determined by α-sources. The energy loss in the 450 μg/cm^2 Teflon wall of the target cell is taken into account. For scattering angles $> 13°$ the recoil protons are no longer stopped in the detector.

Figure 1 shows the locus of events that is characterized by the scattering angle θ determined by the forward detector and the pulse height produced by the recoil in the silicon strip detector. The pulse height predicted from θ and the absolute detector calibration is indicated by the curve. Even at the smallest angles, the energy loss in the wall of the target cell is only 100 keV. The excellent agreement of the observed events with the calculated curve shows that as long as the protons are stopped by the recoil detector, the scattering angle can be determined reliably from the recoil pulse height instead of the forward stack. This feature will be used in analyzing the events between 3° and 5° since these protons penetrate the inner support of the first wire chamber and thus suffer about 0.3° multiple scattering. For $\theta > 13°$ the recoil detector no longer stops the protons. The poor energy resolution in this region is caused by the lack of complete depletion of the detectors and a variation of resistivity between different parts of the detectors.

The most important recent results are summarized below.

a) Target polarization: The target polarization is switched in sign and/or direction (x, y, z) every 2 s. The degree of polarization in the x- and y-direction (Q_x, Q_y) is determined from the asymmetry in count rate associated with polarization reversal. One of the concerns about the use of a target cell is the possibility that radiation damage may alter the surface properties of the cell wall such as to cause depolarization of the atoms in the ≈ 100 wall collisions they suffer before escaping from the cell. No deterioration of target polarization was observed during this run (Fig. 2). Table 1 shows that the target polarization is equal in

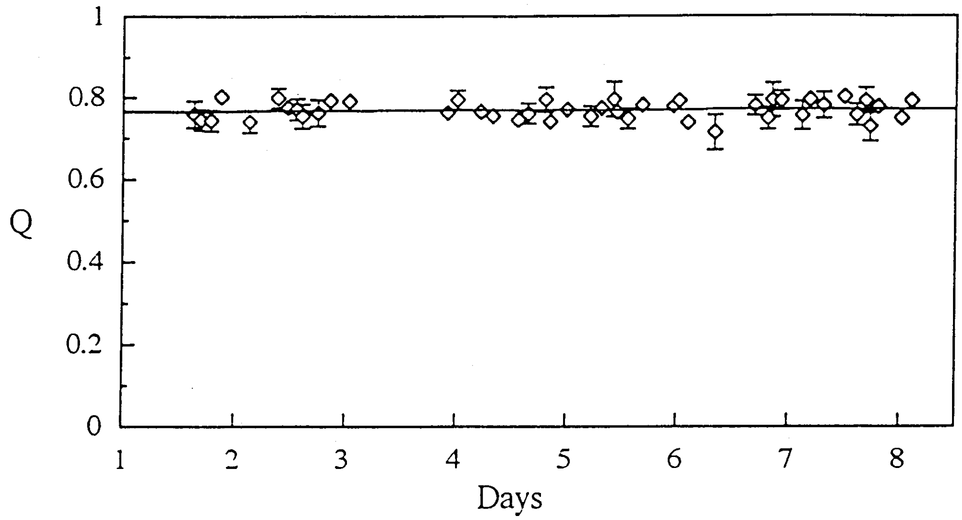

Figure 2. Target polarization Q during a recent one-week run.

Target Polarization	Guide Field Direction B_x	B_y	B_z
Q_x	0.776(5)	0.006(5)	0.006(5)
Q_y	−0.006(5)	0.777(5)	−0.007(5)

Table 1. Average target polarizations Q_x, Q_y for guide fields in the x, y, and z-direction during a recent eight-day run. The numbers in parentheses give the statistical uncertainty in the last digit.

magnitude, independent of the guide field direction ($Q_x = Q_y$), and that the polarization component orthogonal to the desired direction is small. Without the availability of longitudinal beam polarization the longitudinal target polarization (Q_z) can not be measured directly, but based on Table 1 one can assume that Q_z has the same magnitude as the transverse polarizations.

b) Target thickness: The thickness of the polarized target was determined by comparing pp count rates with that for an unpolarized H_2 target of known thickness. The thickness expected from absolute measurements of the atomic beam flux prior to installation of the target at IUCF is $(3.5 \pm 0.3) \times 10^{13}$ H/cm^2, in good agreement with the data shown in Fig. 3.

Besides large polarization, rapid polarization reversal and the absence of unpolarized contaminants, another advantage of the target is that the thickness can be expected to be invariant under changes in sign and direction of polarization. However, earlier runs showed unexpected variation of target thickness when, for example, the guide field in the x-direction was reversed. The reason was the effect of the stray field from the guide field

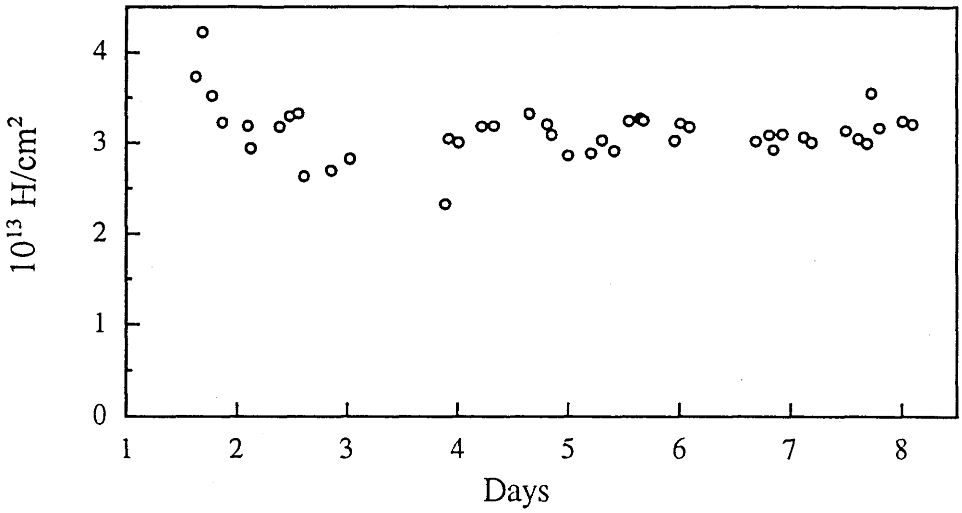

Figure 3. Thickness of the polarized H target during a recent one-week run.

coils on the RF transition unit which rejects one of the hyperfine states in the atomic beam source. After addition of a compensation coil prior to the last run, the variation in target thickness is now less than 0.3%. Thus one can assume that within this accuracy the efficiency of the RF transition is now independent of guide field.

c) Beam polarization and spin flipper: At the beginning of a run, protons of a given polarization (up or down) are accumulated in the ring, followed by a measuring cycle of typically 760 s. In all earlier runs, the beam was dumped after each cycle and beam of opposite polarization was injected. Typically, the up polarization was $P_y = 0.65$ and the down polarization $P_y = -0.70$.

In the most recent run, a spin flipper, described in a separate contribution to this report, was employed. It resulted in significantly improved luminosities with little loss in beam polarization.

d) Detector and beam alignment: An interesting feature of the experiment is that the alignment of the detectors with respect to the beam can be carried out in software after the run. The distance between the two sets of wire chambers is readily measured, but the distance of the wire chambers to the target center is best determined from the data themselves. For this purpose, the proton tracks determined from the wire chambers are projected back onto the x-y plane at the z-location determined by the recoil detectors, producing a hit pattern shown in Fig. 4. The calculation is repeated for different assumed distances between target center and wire chambers. The distance that produces the smallest lateral spread in the hit pattern determines the target position relative to the wire chambers to $\pm$ 0.7 mm. The lateral position of the hit pattern reveals lateral misalignment of the beam relative to the wire chambers, and the disparity in the scattering angle measured by the silicon detectors relative to the forward detectors reveals angle misalignment. These are removed by corresponding software adjustments. Fig. 5 shows beam motion relative to the wire chambers during a one-week run. The centroid of the hit pattern for each run is determined to better than $\pm$ 0.1 mm. The large change in beam

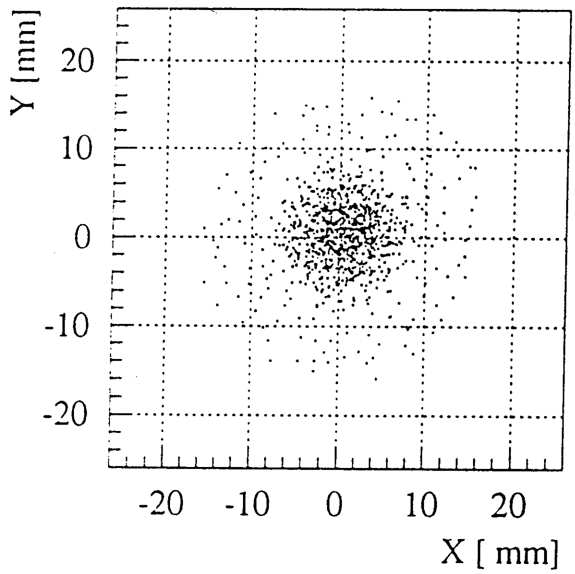

Figure 4. The pattern in the x-y plane at the z-location determined by the silicon strip detector.

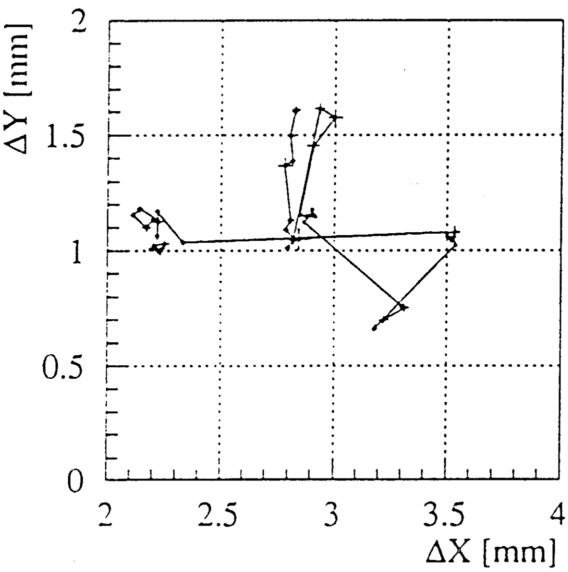

Figure 5. Motion of the beam centroid during a one-week run. The motion is small compared to the 8-mm cell aperture.

position (1.2 mm) from one run to the next was associated with retuning the accelerators after a power failure. Note that the beam motion is small compared to the 8 mm cell aperture. For each run the analysis corrects for these changes.

These diagnostics are sufficiently accurate to permit a determination of beam motion associated with reversal of the guide field over the target. The guide field is less than 4 G, and the effect on the beam is reduced by compensation coils before and after the target. But any change in beam position or angle that is associated with reversal of the target polarization has the potential of introducing a systematic error. For other reasons, runs with polarized target were interspersed with unpolarized target runs of about equal statistical accuracy. These unpolarized runs were used determine the amplitude of beam motion from guide-field reversal. The largest lateral displacement was (22 ± 4) μm in the x-direction associated with the y-guide field, and the largest angular displacement was (51 ± 24) μrad in the y-direction caused by the x-guide field.

e) Background: The choice of the present cell opening was based on studies we performed earlier in which the beam lifetime was measured for different cell acceptances in order to optimize the luminosity of polarized-target experiments. Since the cell limits the acceptance of the ring, one is concerned about background caused by interaction of the beam with the cell wall, which has about 10^9-times more mass than the polarized H in the target. For the present purpose, background is defined as an event that passes all the criteria for a valid pp event but is caused by a process other than pp scattering in the target region. The most likely such process is quasifree scattering (p,2p) from C or F in the cell wall. Several methods were used to investigate background: (i) the target gas was removed and at the same time gas was added to the T-region in order to provide equivalent beam heating; (ii) the H in the target was replaced by He and the number of counts in the H-locus was determined; and (iii) the H in the target was replaced by N_2 on the assumption that the kinematics of (p,2p) events on N would be similar to those on F or C in the cell wall, so that characterization of background events could be based on the N_2 measurements. The last of the three tests turned out to be the most sensitive. A large fraction of the events with N_2 in the target are non-coplanar and are outside the locus in the θ vs. E_{recoil} plane. On the other hand, with the H target very few events are non-coplanar and outside the pp locus (see Fig. 1). Based on this comparison, it was concluded that background is $< 0.2\%$ of the number of good pp events.

f) Results: The most recent run provided about 4×10^6 pp events. An equal amount of data was also obtained in earlier runs taken under much less favorable conditions (large variations in beam current, and in beam and target polarization, etc.). Additional measurements with about the same number of counts were made as a check with unpolarized target.

The determination of beam and target polarization made use of an extrapolation to the present beam energy (197.8 MeV) of an absolute A_y measurement in pp scattering at 183.1 MeV carried out earlier at IUCF. It is expected that the final results will have a statistical uncertainty in the spin correlation coefficients A_{xx}, A_{yy} and A_{zx} of about 0.01, and systematic errors less than 0.005. In addition, the spin correlation coefficients are subject to a scale factor uncertainty of about 2% from the uncertainty in the absolute polarization calibration.

The present results provide the only measurements of A_{xx} and A_{zx} in the energy range 150 MeV to 350 MeV. Previous measurements of A_{yy} have about ten time larger uncertainties than the present results, and were limited to angles above 30°. The most important result obtained here is the demonstration that polarized internal targets in the IUCF Cooler ring permit accurate measurements of spin correlations in the pp interaction over a wide range of angles with good event rates and very low background.